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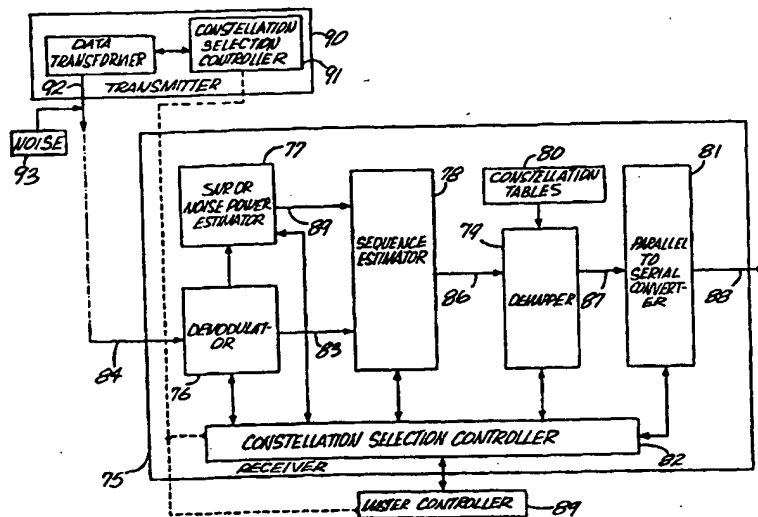
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(54) Title: FRACTIONAL-BIT TRANSMISSION USING MULTIPLEXED CONSTELLATIONS



(57) Abstract

A device of dynamic communication of information allows, on the average, non-integer bits per symbol transmission, using a compact code set or a partial response decoding receiver. A stream of k or $k+1$ data bits is grouped into bit vectors which then are mapped onto corresponding signal constellations forming transmission symbols. Two or more symbols can be grouped and further encoded, so that a symbol is spread across the two or more symbols being communicated. Sequence estimation using, for example, maximum likelihood techniques, as informed by noise estimates relative to the received signal. Each branch metric in computing the path metric of a considered sequence at the receiver is weighted by the inverse of the noise power. It is desirable that the constellation selection, sequence estimation and noise estimation be performed continuously and dynamically.

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FRACTIONAL-BIT TRANSMISSION USING MULTIPLEXED CONSTELLATIONS

RELATED APPLICATION

This patent application claims the benefit of the filing date of U.S. Provisional Patent Application No. 60/106,481 filed October 30, 1998 and entitled CONSTELLATION-MULTIPLEXING CODED MODULATION AND OPTIMUM RECEIVER, the entire contents of which are hereby expressly incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus and method for communicating information using fractional bits-per-symbol signaling rates responsive to communication channel conditions.

2. Description of the Relevant Art

There exist applications for which it is desirable to transmit transmission symbols that each is composed of a number of information bits which may not represent an integer. The signal constellations associated with such transmissions symbols, then, corresponds to non-power-of-two constellation sizes and/or non-integer constellation sizes.

What is needed is a device that affords fractional bits per symbol digital communication approaching a maximum allowable bit rate yet does so in an efficient manner permitting use of compact code sets, or use of a partial response receiver. Before proceeding with a description of exemplary embodiments, it should be noted that the various digital signaling concepts described herein--with the exception, of course, of the inventive concept itself--are all well known in, for example, the digital radio and voiceband data transmission (modem) arts and thus need not be described in detail herein. These include such concepts as multidimensional signaling using 2N-dimensional channel symbol constellations, where N is some integer; trellis coding; fractional coding; scrambling; passband shaping; equalization; partial response; Viterbi, or maximum-likelihood, decoding; Quadrature Amplitude Modulation(QAM); Orthogonal Frequency Division Multiplexing (OFDM), etc.

SUMMARY OF THE INVENTION

The invention herein provides communication devices affording non-integer bits per symbol digital communication at bit rates approaching optimality for a given set of constraints, using a compact code set or utilizing partial response receiver. In general, the devices which embody the present invention, can include a transmitter, a receiver, or both. These devices manipulate arriving data from a data bit form to a transmission symbol form in a data transformer, advantageously using knowledge of one or more data channel conditions to dynamically and continuously adjust the constellations used to represent the transmitted data. Successive transmission symbols each can contain a varying number of data bits, as governed by

1 a constellation selection controller that is connected with the data transformer. Successive
symbols can be transmitted at different time stamps or at different frequency locations. A
performance metric estimate can be used to determine which constellation is to be used. A
5 receiver using a sequence estimation technique can optimally decode the received signals given
the condition that (i) the soft-decision symbols at the receiver are correlated through the
employed channel coding and/or through the introduction of defined partial channel response,
and (ii) there exists knowledge of the signal-to-noise ratio (SNR) metric of each soft-decision
symbol. Having these techniques, a transmitter, for example, can transmit on the average non-
10 integer information bits per symbol, say between k and $k+1$, with the multiplexing of a first
constellation, representing k bits per symbol, and a second constellation, representing $k+1$ bits
per symbol, such that the desired non-integer information-bit-per-symbol transmission is
achieved. It is desired that such multiplexing be done continuously and dynamically.
Furthermore, the digital communication facilitated by the invention herein is not limited to
15 temporal sequence transmission (i.e., the time domain) but also can be used in the frequency
domain, or both.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrative of an exemplary embodiment of the present invention.

20 Figure 2 is a block diagram illustrative of a first exemplary embodiment of the present invention, in the form of a transmitter.

Figure 3 is a block diagram illustrative of a first exemplary embodiment of the present invention, in the form of a receiver implementing sequence and noise estimation.

Figure 4 is a block diagram of another exemplary embodiment of a transmitter illustrative
25 of a trellis encoding implementation as an option.

Figure 5a is a block diagram illustrative of a exemplary transmitter embodiment intended
for single symbol encoding.

Figure 5b is a block diagram illustrative of a exemplary transmitter embodiment intended
for multiple symbol encoding.

30 Figure 6 is a block diagram of another exemplary embodiment of a receiver illustrative
of an implementation of demodulation, sequence and noise estimation.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

35 The present invention provides for processing communication data using a number of
information of data bits per transmission signal, which may be a non-integer, with realizable
integer or power-of-two constellation sizes. A forward error correction (FEC) code with a proper
code rate can be added such that the information bit rate could further be adapted to a signal
constellation size that is an integer or a power-of-two. Depending on the required resolution of

1 the average information bits being transmitted in each symbol, a set of FEC codes can be
employed to accommodate the desired code rates. However, this resolution can translate into an
undesirably large set of embedded codes needed to achieved the target transmission metrics
which, for rate-adaptive applications, complicates the design and rate adaptation procedures. In
5 the invention herein, as few as one fixed trellis code may be used to achieve the desired
resolution on the transmission information bits per symbol, simplifying the associated device
designs and communication protocols. In the cases where FEC coding is not desirable, or not
necessary, the desired resolution on the transmission bits per symbol still can be optimally
accommodated through the use of a sequence estimator at its receiver to decode a pre-defined
10 partial response formed for the soft-decision symbols at the receiver.

One application for which this communication data processing may be desirable is
rate-adaptive communication service. In a rate adaptive service in which the maximum allowable
bit rate is decided before service sessions start and a non-integer bits per symbol might be
required to achieve this maximum bit rate. By doing so, non-integer information bits per symbol
15 can be transmitted.

For the purposes herein, the term channel noise will include additive white Gaussian noise,
colored Gaussian noise, or both; scintillation noise; shot and impulse noise; all forms of channel
attenuation; signal fading and distortion; interference such as intersymbol interference; and any
other entity that acts to deviate or disperse the data signal actually received from the data signal
20 originally transmitted, both additive and multiplicative, regardless of stationarity or orthogonality.

An exemplary embodiment of the present invention is seen in Figure 1. Communication
device 1 is interposed into a data channel which is represented by communication channel input
data stream 2 and communication channel output data stream 3. The data channel can transmit
both the desired information as well as undesirable channel noise that is imposed upon the data
25 stream due to one or more channel conditions.

Communication device 1 includes data transformer 4 and controller 5, and can be
representative of a transmitter or a receiver. Data transformer 4 manipulates information between
data bits and transmission symbols. In an instance where device 1 represents a transmitter, input
data stream 2 can be the data bits intended to be transmitted and output data stream 3 can be the
30 transmission symbols transmitted through the data channel. In a case where device 1 represents
a receiver, input data stream 2 can be the transmitted symbols as detected at the receiver, and
output data stream 3 can be the recovered data bits which correspond to the data bits entering a
transmitter. Device 1 is not constrained to operate solely in the time domain, but may operate
in other domains including, for example, frequency domain. Also, device 1 is operative where
35 data is both transmitted and received in both time and frequency domains.

According to the present invention, the number of data bits contained in a transmission
symbol is selectable, responsive to the channel condition. The selection of the number of data
bits in a transmission symbol is governed by controller 5. It is desired that the channel condition

1 to which controller 5 responds, and by which the number of data bits is selected and processed
by data transformer 4, be a preselected channel condition metric. Desirable metrics for the
representation of channel condition include the signal-to-noise ratio of the received symbol
and/or the power of the noise in a received symbol. The desirable metric may further be
5 restricted by preselected constraints such as, for example, a bit error rate (BER). Data bit
selection also can be driven by master controller 8, which may be external to device 1, and which
itself may be responsive to a state of the data channel, such as the SNR of the received signal.
Where device 1 is a transmitter, controller 8 may be operably connected to a corresponding
receiver. It also is desired that channel state monitoring be continuous, and that selection of the
10 number of data bits used to form a transmission symbol be adaptive to a present condition of the
data channel.

Having described the general inventive concept, a more detailed embodiment will now be
described. In Figure 2, transmitter 11 includes data transformer 12 and constellation selection
controller 18. Data transformer 12 can include bit parser 13, encoder and constellation mapper
15 17, and constellation table 16. Constellation selection controller 18 employs control signal 15 to
govern the operation of parser 13, as well as the operation of encoder and mapper 17. For
example, relative to the operation of bit parser 13, controller 18 can govern the selection of the
number of data bits per bit vector; relative to the operation of encoder and mapper 17, controller
18 can govern the selection of the constellation alphabet used during a particular interval, and the
20 level of redundancy and correlation imposed upon the transmission symbols prior to transmission
via channel output data stream 19.

In Figure 3, receiver 24 includes a noise estimator 28, a sequence estimator 26, a
constellation selection controller 31, a constellation table 34, and a parallel-to-serial converter
36. It will be readily apparent that data transformer 29, which can include estimator 26, table 34
25 and converter 36 is functionally equivalent to data transformer 4 in Figure 1. Although noise
estimator 28 is illustrated to be external to data transformer 29, yet within receiver 24, it also may
be grouped within data transformer 29, or even be external to receiver 24. It is desirable that
constellation selection controller 31 be responsive to a channel condition, such as the
signal-to-noise ratio or strength of received symbol and noise 25.

30 The transmission symbols carried upon the received signal 25 are known to be corrupted,
or tagged, by some amount of channel noise. Noise estimator 28 is employed to quantify the
amount of channel noise present in signal 25. Noise estimate 37 is received by sequence
estimator 26 such that a reasonably good estimate of the transmission symbol originally
transmitted to receiver 24 can be derived. Although one skilled in the art would recognize that
35 many implementations of received signal estimation can be used to effect recovery of the
transmitted signal, the skilled practitioner also would realize that it is desirable to employ a
maximum likelihood sequence estimator (MLSE) as sequence estimator 26 in receiver 24 for
optimized data reception. One such MLSE can be realized with a Viterbi decoder. A MLSE

1 typically is used for decoding a convolutional code, a trellis code, as well as received symbols
with partial response, and can be advantageous in the presence of channel noise such as
intersymbol interference. In decoding a constellation-multiplexed (CM) signal, such as
described herein, a MLSE can take advantage of the SNR information of each symbol at the
5 receiver and produce a maximum likelihood estimation of CM signals that can approach
optimality.

Constellation selection controller 31 can assign each received symbol in the MLSE with
an appropriate constellation mapping, and its associated data bits per transmission symbol. Based
on the assigned constellation mapping, not only does the MLSE compute path metrics of a
10 received symbol accordingly, it also can scale the branch metrics according to the maximum
likelihood estimation criterion. As above, constellation selection controller 31 directs parallel-to-
serial converter 36 to output corresponding data bits in each symbol. It is desirable for
synchronization to be established between the constellation selection controller of a transmitter
and the constellation selection controller of a corresponding receiver.

15 Another exemplary embodiment of the present invention, in the form of
constellation-multiplexed transmitter 40, is illustrated in Figure 4. Here transmitter 40 includes
a bit parser 41, trellis code encoder 45 as an option, constellation mapper 47, constellation tables
48, modulator 51, and constellation selection controller 49. Furthermore, controller 49 itself may
be governed by master control 53. The master control could be a corresponding controller on a
20 corresponding receiver.

Without loss of generality, it is useful to illustrate the principles of the present invention
with a specific example where k and p/q information bits are transmitted per symbol, and where
 k , p and q are integers, and p is smaller than q . At the transmitter 40, bit parser 41 can receive
an input bit stream 42 at a rate of k and p/q bits per symbol. Bit parser 41 selectively partitions
25 incoming data bits 42 into bit vectors 43. It is desired that the partitioning be performed
continuously. Parser 41 sends bit vector 43 having, for example, either k or $k+1$ bits, to an
optional trellis code encoder 45 under the direction of constellation selection controller 49. After
encoder 45 imposes a predetermined correlation between successive output bit vectors 43 from
bit parser 41, the resultant encoded vectors 46 are then mapped to corresponding transmission
30 symbols 50 by way of constellation mapper 47.

Constellation mapper 47 can employ constellation table 48 to map each vector into
transmission symbol 50 that is a member of one or more preselected symbol alphabets which
themselves can correspond with a symbol constellation. Constellation selection controller 49 can
continuously govern the number of data bits grouped into a bit vector according to a particular
35 predetermined pattern. In the exemplary embodiment of the invention herein, each
predetermined pattern is representative of a preselected signal constellation, for example, k or
 $k+1$ bits per symbol.

Note that constellation mapper 47 can map vectors 43 directly from bit parser 41. In this

1 case, the system is an uncoded one, and no correlation may be imposed on transmitted symbols. The correlations will be imposed on received symbols at its receiver by forming a pre-defined partial response for the received symbols. However, in some embodiments, where it is desirable to employ encoder 45, bit parser 41 first directs the bit vector to encoder 45. Encoder 45 imparts
5 a pre-determined correlation among data, in this case, between successive output vectors.

Constellation selection controller 49 can govern the selection between k and $k+1$ data bits in bit vector 43 from bit parser 41, such that the average transmitted bits per symbol 50 is k and p/q . Controller 49 also can direct the trellis code encoder 45, or constellation mapper 47, or both, to choose the desired constellation size based on the number of bits to be transmitted via the
10 transmission symbol at hand. Where it is desired to further process transmission symbols 50 into signals 52 better suited for a particular transmission format, modulator 51 may be used. Responsive to modulator 51, consecutive symbols can be transmitted at different time stamps, or at different frequency locations, or both.

As in previous embodiments of the present invention constellation selection controller 49
15 is desired to be responsive to a sensed channel condition 54; or to a master control 53 which may be external to transmitter 40, for example, from a corresponding receiver.

The optional trellis code used in a system according to the invention herein could be a single symbol code or a multi-symbol code. Figure 5(a) shows an encoder 50 that implements a single-symbol trellis code in which c data bits 51, out of each k or $k+1$ data bits 52, are encoded to c' data bits 53 through, for example, a convolutional encoder 54. Constellation mapper 55
20 converts the encoded data bits 53 and uncoded data bits 51 into a transmission symbol 56 in the desired information format. Figure 5(b) shows an example of an encoder 60 implementing an m -symbol trellis code, in which k or $k+1$ input data bits 61 arrive corresponding to a single transmission symbol with m symbols 67 being buffered in symbol buffer 62 before being
25 encoded. Among these input bits of the m transmission symbols 67, c data bits 65 are encoded to c' data bits 68 again, for example, through encoder 69 which may be a convolutional encoder. These c' data bits 68 are combined with uncoded data bits 64 and are mapped in constellation mapper 63 into m consecutive transmission symbols 71 in preparation for transmission. Note that the m consecutive transmission symbols do not necessarily use the same constellation.

30 In Figure 6, receiver 75 includes a demodulator 76, noise estimator 77, sequence estimator 78, demapper 79, constellation tables 80, parallel-to-serial converter 81, and constellation selection controller 82. Demodulator 76 recovers received soft-decision symbols r_m 83 from received signal 84, which signal 84 contain the original transmission symbols 92 from the transmitter 91, corrupted by channel noise 91. Transmission symbols 92 may be transmitted in
35 signal 84 at different time stamps, different frequency locations, or both. In the case where the transmission symbols 84 were not first encoded in the transmitter 90, it is desired that demodulator 76 forms a partial response on the received symbols so that a defined correlation, which may exist between received soft-decision symbols r_m 83, can be utilized. It is desirable

1 for noise estimator 77 to associate a noise estimate metric 89 with each soft-decision symbol 83;
the noise estimate metric being, for example, a noise power estimate metric or a SNR estimate
metric.

5 Sequence estimator 78 determines recovered data symbols $a_{k,m}$ 86 on the basis of the
predetermined correlation among consecutive symbols 83 output by demodulator 76. It is desired
to incorporate noise estimate metric 89 in extracting a sequence of symbols 86 from symbols 83.
Indeed, it is desired to use a MLSE as sequence estimator 78, and that noise estimate metric 89
be used to compute the likelihood metric of each considered sequence. Where a sequence is
10 selected to be the most likely transmitted sequence based on the likelihood metric, the quality of
recovered data symbols 86 can approach optimality, in the maximum likelihood sense.

One method for describing the operation of MLSE 78 is as follows:

In general, it is desirable for sequence estimator 78 to
find a sequence $\{a_{k,m}\}$ at its output such that either of the
following noise-power weighted Euclidean distances is minimized:

$$15 \quad \sum_m \frac{(r_m - a_{k,m})^2}{N_m}$$

or

$$20 \quad \sum_m \frac{SNR_m (r_m - a_{k,m})^2}{S_{A_m}}$$

where

each $a_{k,m} \in \{a_{k,m}\} \equiv A_m$

25 m is a symbol index;

k is an alphabet index;

\hat{k} is the decided alphabet index;

30 A_m is a set of alphabets used for symbol m ;

N_m is the estimated noise power associated with symbol r_m ;

35 SNR_m is the SNR associated with the symbol r_m ; and

S_{A_m} is the average signal power associated with the alphabet
set used for r_m .

1 This is because in the presence of, for example, noise whose power varies across different
symbols, the maximum likelihood decoding essentially consists of finding that particular path
5 through the trellis with the minimum-weighted-squared-Euclidean distance to the received
sequence, where, in computing the path metric, each branch metric is weighted by the inverse of
the noise power associated with the soft-decision symbol. Recovered data symbols 86 are
received from MLSE 78 by demapper 79 and, in conjunction with constellation tables 80, maps
a recovered symbol 86 onto a data bit vector 87, the size of which vector may vary between
10 successive symbols. Tables 80 typically corresponds to similar constellation tables in transmitter
90. As bit vectors 87 are generated by demapper 75, parallel-to-serial converter 81 converts
vectors 87 into a bit stream 88 that corresponds to the data bit stream originally input to
transmitter 90. Similar to the operation of constellation selection controller 49 in Figure 4,
constellation selection controller 82 can inform demodulator 76, sequence estimator 78,
15 demapper 79, and parallel-to-serial converter 81 of the pertinent details of the constellation being
implemented at a particular moment, such as the current symbol alphabet and the number of bits
in recovered symbol 86. As with a constellation selection controller 91 in transmitter 90, it is
desirable for controller 82 to allow different sets of symbol alphabets and provide a variable
number of bits in a symbol, responsive to a channel state. It is desirable to provide some form
of synchronization between the constellation selection controller 91 in transmitter 90, and the
20 constellation selection controller 82 in receiver 75.

Although the invention is illustrated herein as being implemented with discrete functional
building blocks, e.g., trellis encoders, constellation mappers, etc., the functions of any one or
more of those building blocks can be carried out using one or more appropriate programmed
processors, digital signal processing (DSP) chips, etc. It should be noted that the principles of
25 the invention are also applicable to other areas of communications. For example, the principles
of the invention can also be applied to the design of modems for use in data communications, to
fading channel applications, and so on.

The various constellations, bit and baud rates, and other parameters are, of course, merely
illustrative. Moreover, the invention can be described herein in the context of multiple
30 amplitude/multiple phase constellations, conventionally known as "QAM", it is equally
applicable to other types of constellations, such as constant amplitude/multiple phase
constellations, such as M-PSK and M-DPSK. The device and method according to the method
herein provides for symbols to be transmitted across the channel at different time stamps (such
as using a QAM technology); at different frequency locations; or through a combination of both
35 (such as using an OFDM technology). Additionally, the invention described herein may be
applied to contexts of voiceband data transmission, cellular mobile radio, digital microwave
radio, satellite communications, wire communications, wireless communications, and the like.

1 The foregoing merely illustrates the principles of the invention, and it will thus be
2 appreciated that those skilled in the art will be able to devise various alternative arrangements
3 which, although not explicitly described herein, embody the principles of the invention within
4 the spirit and scope of the following claims.

5 The following claims are hereby incorporated into the specification, with each claim
6 standing on its own merits, and each claim being subject to the same construction as if it
7 were set forth in a separate application. The claims are intended to cover all variations
8 of the invention which are within the scope of the invention, and which are not
9 expressly excluded by the prior art.

10 The following claims are hereby incorporated into the specification, with each claim
11 standing on its own merits, and each claim being subject to the same construction as if it
12 were set forth in a separate application. The claims are intended to cover all variations
13 of the invention which are within the scope of the invention, and which are not
14 expressly excluded by the prior art.

15 The following claims are hereby incorporated into the specification, with each claim
16 standing on its own merits, and each claim being subject to the same construction as if it
17 were set forth in a separate application. The claims are intended to cover all variations
18 of the invention which are within the scope of the invention, and which are not
19 expressly excluded by the prior art.

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21 standing on its own merits, and each claim being subject to the same construction as if it
22 were set forth in a separate application. The claims are intended to cover all variations
23 of the invention which are within the scope of the invention, and which are not
24 expressly excluded by the prior art.

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26 standing on its own merits, and each claim being subject to the same construction as if it
27 were set forth in a separate application. The claims are intended to cover all variations
28 of the invention which are within the scope of the invention, and which are not
29 expressly excluded by the prior art.

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31 standing on its own merits, and each claim being subject to the same construction as if it
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34 expressly excluded by the prior art.

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36 standing on its own merits, and each claim being subject to the same construction as if it
37 were set forth in a separate application. The claims are intended to cover all variations
38 of the invention which are within the scope of the invention, and which are not
39 expressly excluded by the prior art.

1 CLAIMS

1. A communication device for communicating data through a data channel, the communication device comprising:

5 a. a data transformer for manipulating the data between data bits and a transmission symbol, the transmission symbol containing a selectable number of the data bits, and the data transformer being operably connected with the channel; and

10 b. a controller for determining the selectable number of data bits constituting the transmission symbol, the controller being connectable to the data transformer, the controller determining the selectable number of data bits in response to a condition, and the data transformer being responsive to the controller.

15 2. The communication device of claim 1, wherein the transmission symbol comprises one data symbol, the data symbol having the selectable number of data bits represented therein.

3. The communication device of claim 1, wherein the transmission symbol comprises a plurality of data symbols, selected ones of the plurality of data symbols having the selectable number of data bits represented therein.

20 4. The communication device of claim 3 wherein the controller reversibly groups the number of data bits into ones of the plurality of data symbols in the response to the channel condition, the selectable number of data bits in the data symbol corresponding to a predetermined pattern being representative of a preselected signal constellation.

25 5. The communication device of claim 4 wherein the data transformer selects successive ones of the plurality of data symbols according to one of a preselected coding method and an unencoded method, in the response to the controller, the controller being responsive to the channel condition.

30 6. The communication device of claim 5 wherein the data transformer dynamically selects a predetermined correlation between successive ones of the plurality of data symbols in the response to the controller, the controller being responsive to the channel condition.

35 7. The communication device of claim 5 wherein the data transformer continuously selects a predetermined correlation between successive ones of the plurality of data symbols in the response to the controller, the controller being responsive to the channel condition.

1 8. The communication device of claim 5 wherein the data transformer selects a predetermined correlation between successive ones of a plurality of transmission symbols in the response to the channel condition, according to a preselected coding method.

5 9. The communication device of claim 5, wherein the preselected coding method is constellation-multiplexed coding.

 10. The communication device of claim 8, wherein the preselected coding method is constellation-multiplexed coding.

10 11. The communication device of claim 1, wherein the channel condition comprises at least one of received power, signal-to-noise ratio, and an input from a master control.

 12. The communication device of claim 1, wherein the controller is responsive to the
15 channel condition in a preselected domain.

 13. The communication device of claim 12 wherein the channel condition comprises at least one of received power, signal-to-noise ratio, and a control master signal.

20 14. The communication device of claim 12, wherein the preselected domain comprises one of a time domain and a frequency domain.

 15. The communication device of claim 13, wherein the preselected domain comprises one of a time domain and a frequency domain.

25 16. The communication device of claim 13, wherein the signal-to-noise ratio comprises one of transmitted power, channel attenuation, noise, and interference.

30 17. The communication device of claim 1, wherein the number of data bits is at least one of a non-power of two and a non-integer.

 18. The communication device of claim 17, wherein the transmission symbol is representable by a plurality of symbol constellations.

35 19. The communication device of claim 8, wherein the communication device is a transmitter, the data transformer imparts the predetermined correlation between the successive ones of the plurality of data symbols, the number of data bits is at least one of a non-power of two and a non-integer, the transmission symbol is representable by a plurality of symbol

1 constellations, and the preselected coding method is constellation-multiplexed coding.

20. The communication device of claim 19, wherein the data transformer further comprises:

- 5 a. a bit parser for grouping the selectable number of data bits into the ones of the plurality of data symbols, the bit parser being governed by the controller; and
- b. a constellation mapper for mapping the ones of the plurality of data symbols into the transmission symbol, the constellation mapper mapping in response to the controller, the controller being responsive to a channel condition.
- 10

21. The communication device of claim 20, further comprising an encoder operably interposed between the bit parser and the constellation mapper, the encoder encoding, in the response to the controller, the selected ones of the plurality of data symbols into the transmission symbol and imparting the predetermined condition thereupon, the controller being responsive to the channel condition.

15

22. The communication device of claim 21 wherein the encoder is a convolutional encoder.

20 23. The communication device of claim 20 further comprising a bit buffer operably connected with the bit parser and the constellation mapper for buffering a selectable group of data symbols.

24. The communication device of claim 23, further comprising an encoder operably interposed between the bit buffer and the constellation mapper, the encoder encoding, in the response to the controller, the selected ones of the plurality of data symbols into the transmission symbol and imparting the predetermined condition thereupon, the controller being responsive to the channel condition.

25

25. The communication device of claim 24 wherein the encoder is a convolutional encoder.

30

26. The communication device of claim 8, wherein the communication device is a receiver, the transmission symbol is representable by a plurality of symbol constellations, the data transformer detecting the predetermined correlation between the successive ones of the plurality of data symbols and extracting the selected number of data bits thereby, the number of data bits is at least one of a non-power of two and a non-integer, and the preselected coding method is constellation-multiplexed coding.

35

a. a noise estimator, operably connected with the data channel and governed by the controller, for estimating a noise metric associated with the transmission symbol; and

b. a sequence estimator, operably connected with the noise estimator and governed by the controller, detecting the predetermined correlation between the transmission symbols and the selected number of data bits; and using the noise metric to filter the channel noise from the received signal, extracting the transmission symbol thereby.

28. The communication device of claim 27, wherein the sequence estimator comprises a maximum likelihood sequence estimator.

29. The communication device of claim 28, wherein the maximum likelihood sequence estimator comprises a Viterbi decoder.

30. The communication device of claim 28, wherein the data transformer further comprises a constellation demapper for demapping the transmission symbols into the selected number of data bits, the demapper being operably connected with the maximum likelihood sequence estimator and governed by the controller.

31. The communication device of claim 26, wherein the received signal is a modulated received signal, and wherein the data transformer further comprises a demodulator operably connected with the data channel, the noise estimator, and the sequence estimator, and governed by the controller, the demodulator restoring at least a portion of the transmission symbols from the modulated received signal.

32. The communication device of claim 27 wherein the sequence estimator employs soft-decision decoding to detect the predetermined correlation.

33. The communication device of claim 32, wherein the received signal has a trellis encoding superimposed thereupon; and the soft-decision decoding includes finding a path through the trellis encoding with a minimum-weighted-squared-Euclidean distance to the transmission symbol from the received signal.

34. The communication device of claim 31, wherein the demodulator further performing a correlative-level decoding.

1 43. The communication device of claim 42, wherein the demodulator further performing a correlative-level decoding.

5 44. The communication device of claim 43, wherein the correlative-level decoding includes a partial-response decoding.

10 45. The communication device of claim 14, wherein the preselected domain comprises time domain and frequency domain; and wherein the transmission symbol is modulated using an orthogonal frequency division multiplexing technique.

 46. The communication device of claim 15, wherein the preselected domain comprises time domain and frequency domain; and wherein the transmission symbol is modulated using an orthogonal frequency division multiplexing technique.

15 47. A communication device comprising:
 a. a variable bit rate data to symbol transformer; and
 b. a controller for selecting a bit rate in response to a condition.

20 48. A data communication method, comprising the steps of:
 a. sensing a condition;
 b. determining a desired variable bit-per-symbol transmission rate responsive to the condition;
 c. transforming data reversibly from data bits to symbols; and
 d. communicating the symbols at the desired variable bit-per-symbol rate.

FIGURE 1

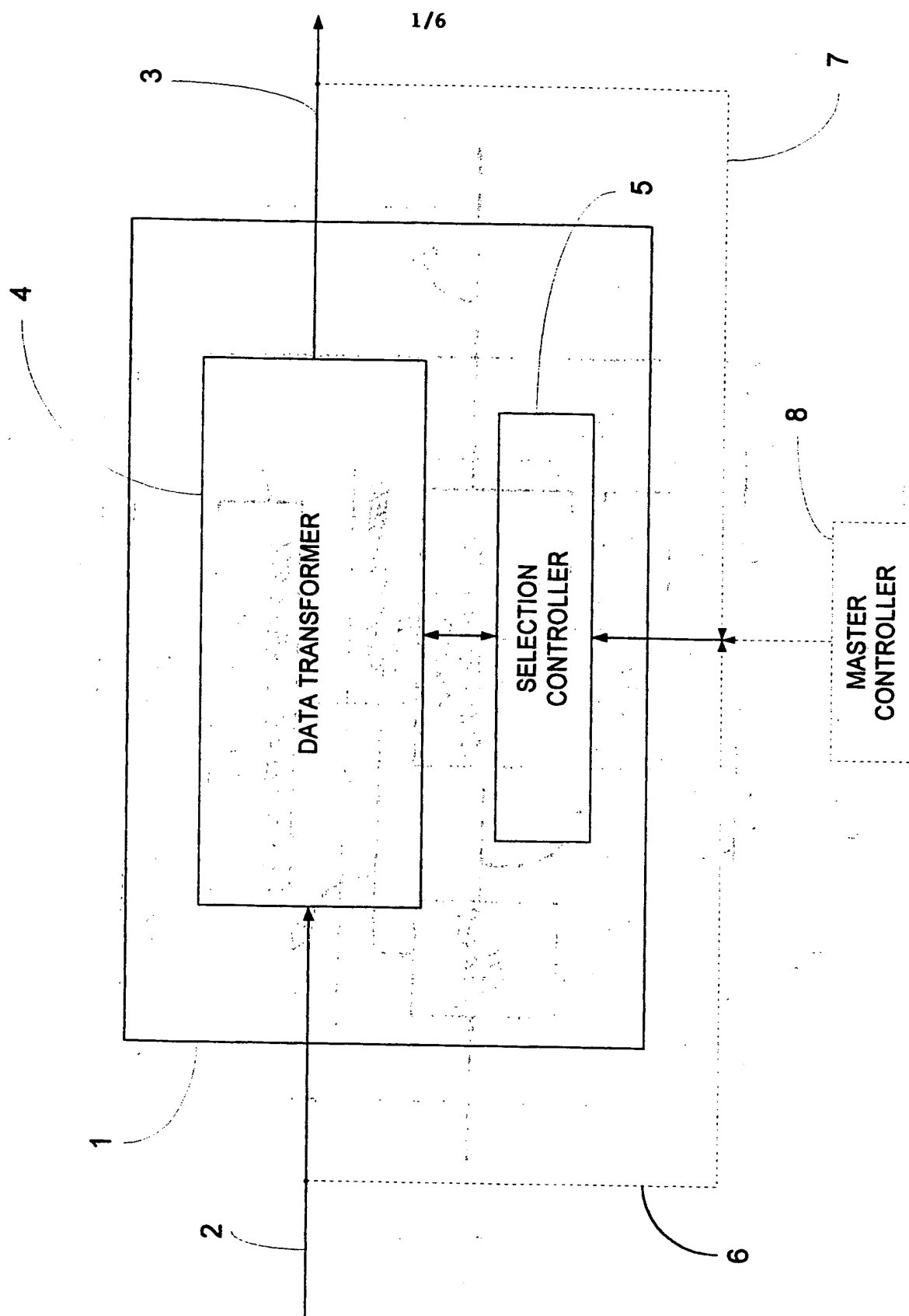


FIGURE 2

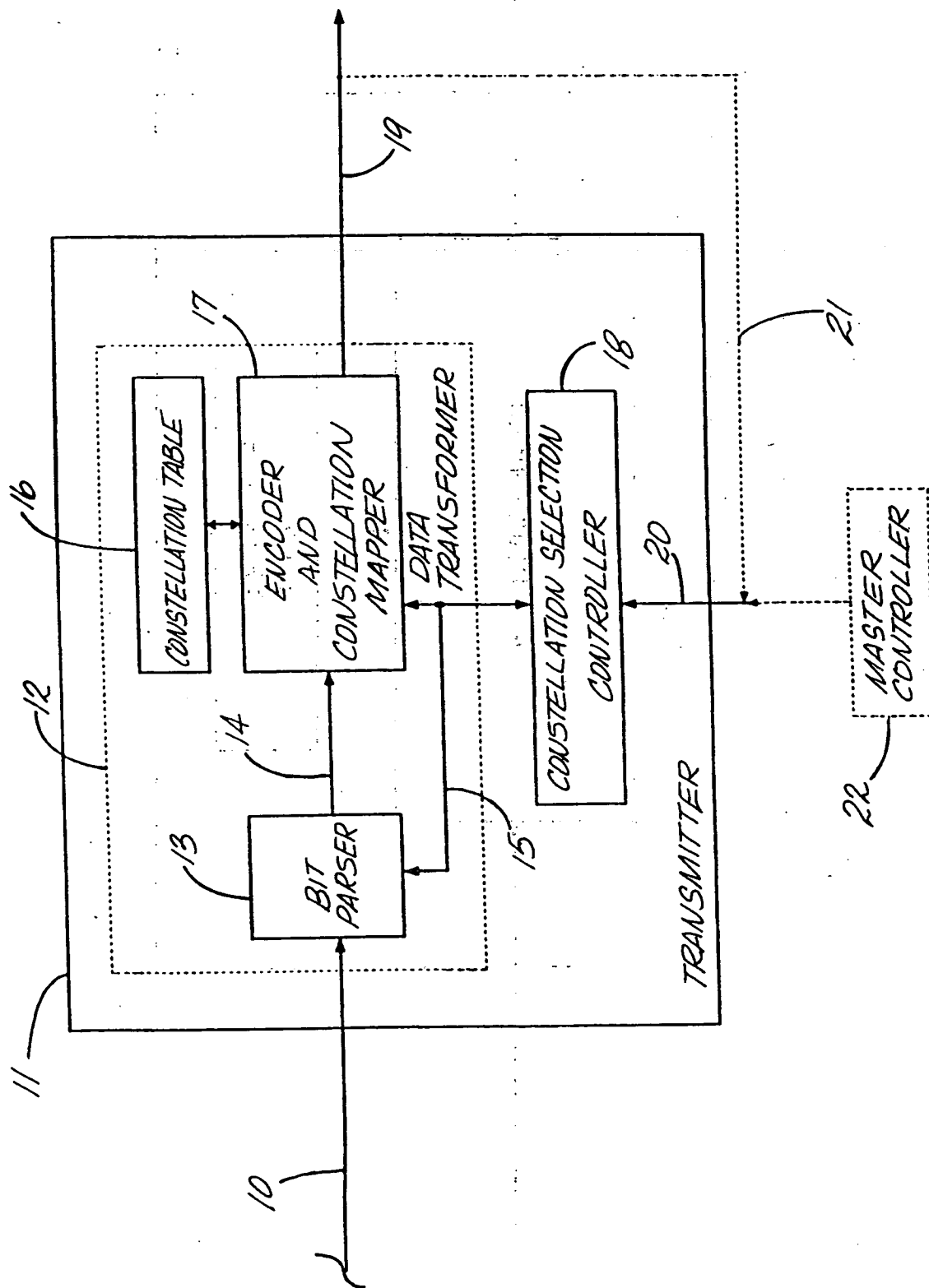


FIGURE 3

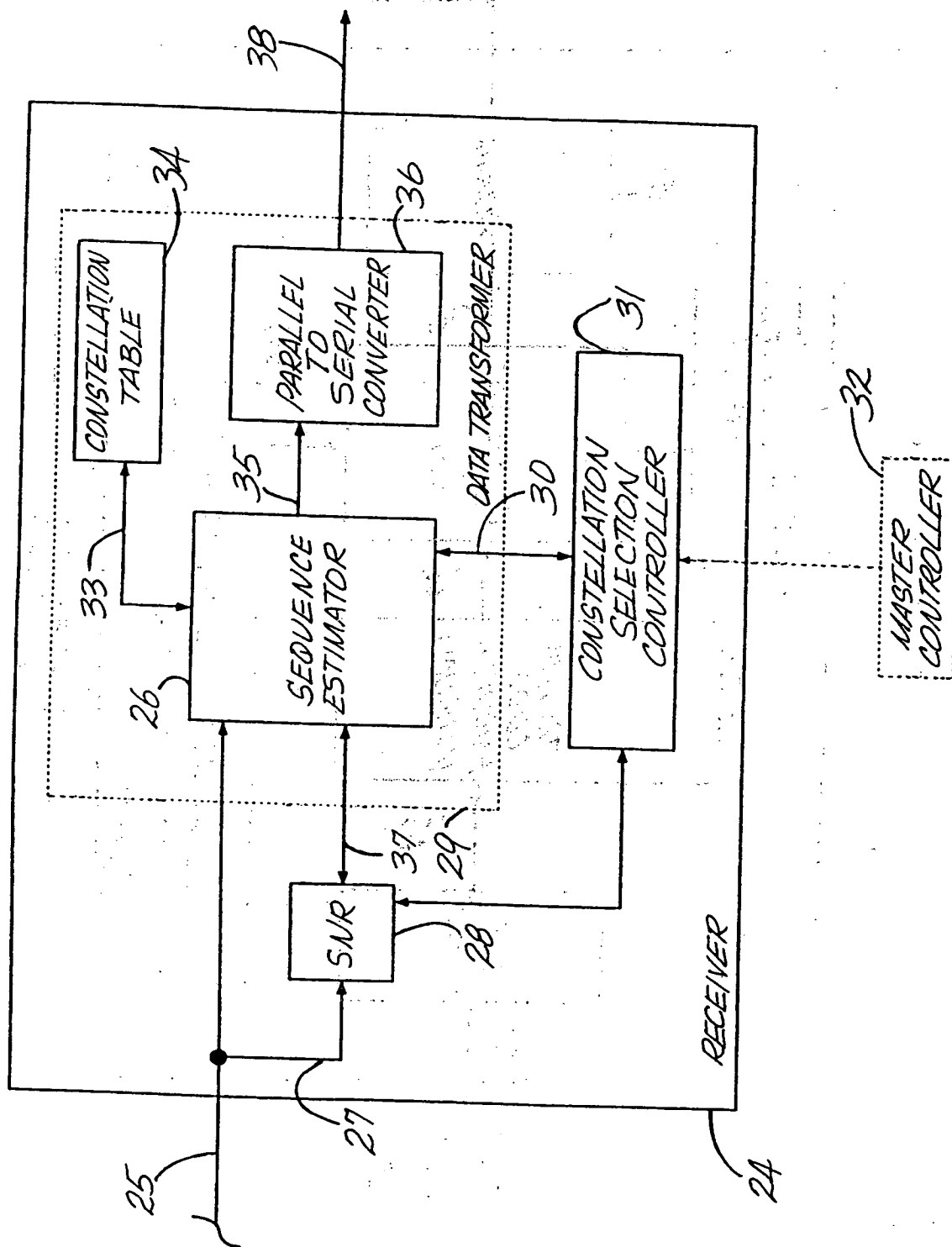
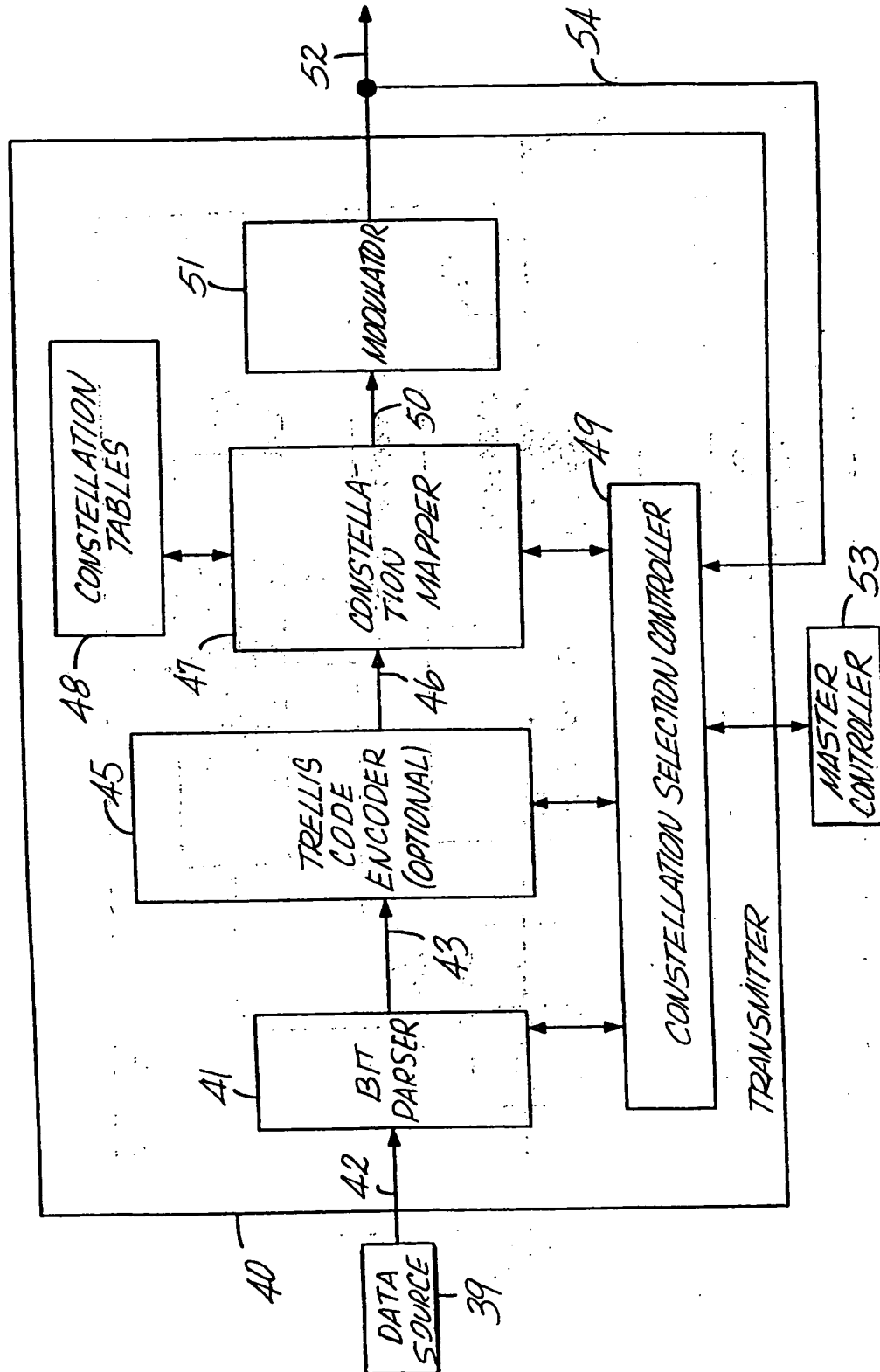


FIGURE 4



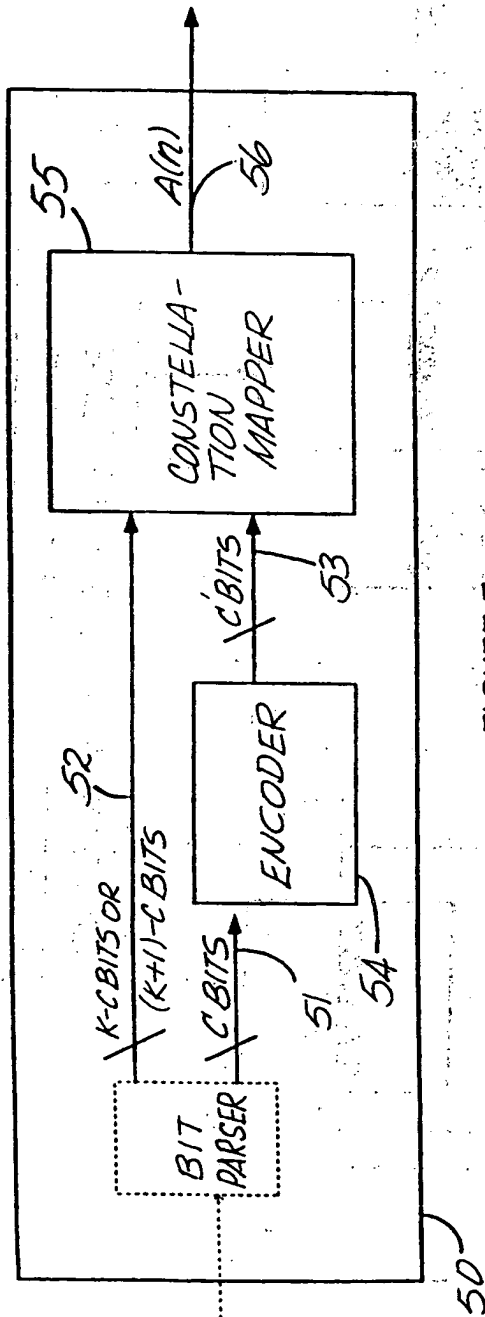


FIGURE 5a

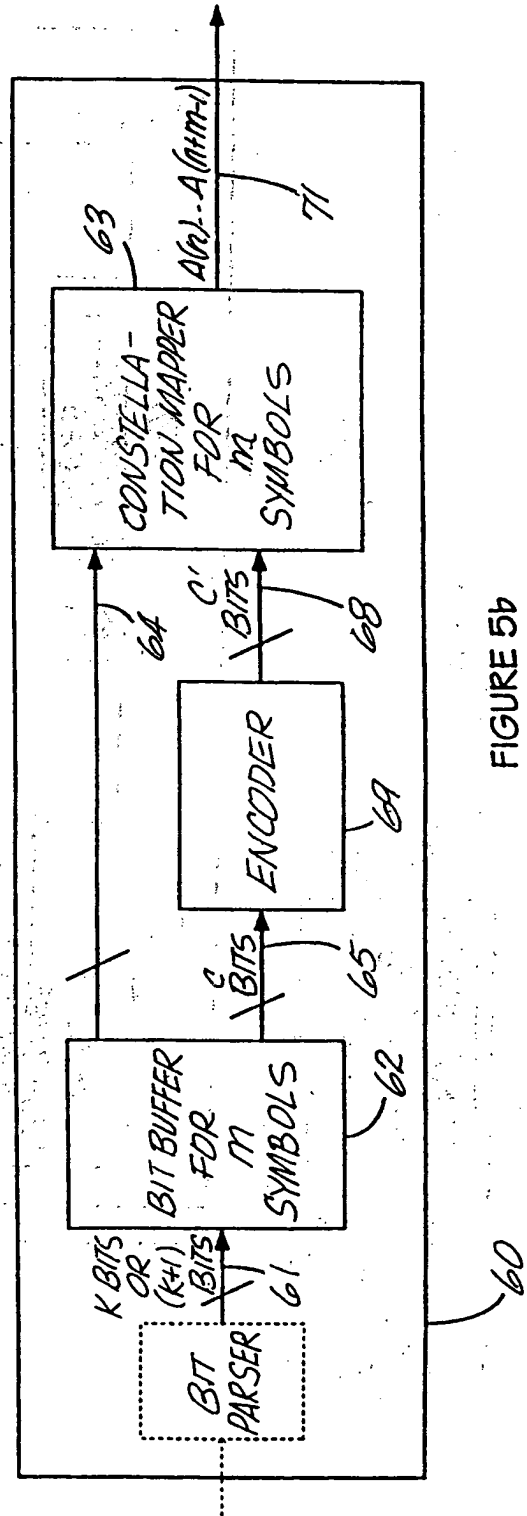
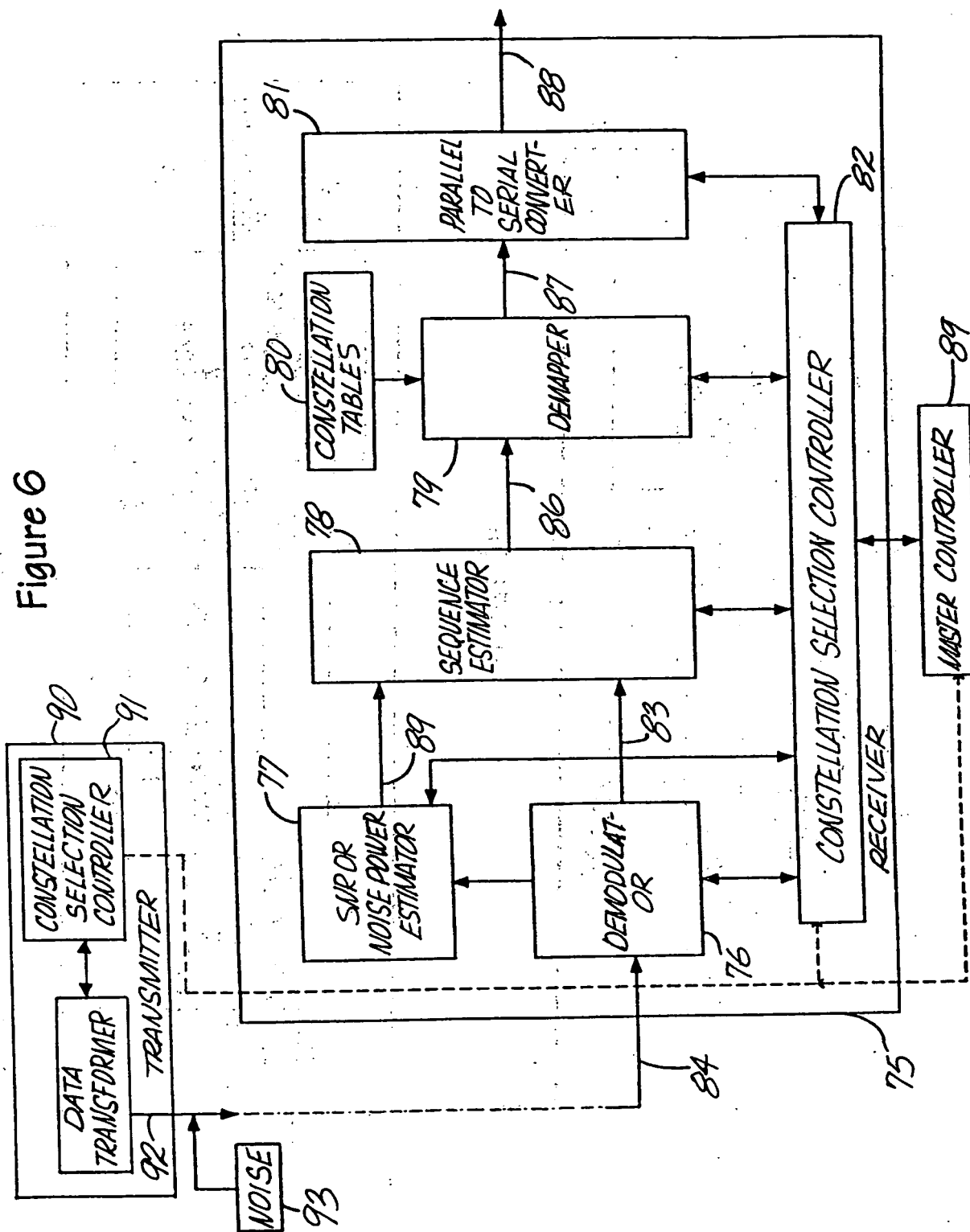


FIGURE 5b

Figure 6



INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/25363

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/34 H04L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 185 763 A (KRISHNAN VEDAVALLI G) 9 February 1993 (1993-02-09) column 2, line 23 - line 29 column 5, line 36 - line 39 column 5, line 44 - line 45 column 6, line 65 - column 7, line 2 column 7, line 12 - line 18 column 8, line 5 - line 19 column 10, line 37 - line 44 column 11, line 4 - line 19 column 29, line 59 - line 63	1-33, 36-42, 47, 48
Y	figures 6A, 6B, 9, 10 --- -/-	34, 35, 43-46

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

24 February 2000

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 5 598 435 A (WILLIAMS RICHARD G C) 28 January 1997 (1997-01-28) abstract column 1, line 43 - line 57 column 2, line 1 - line 4 column 3, line 1 - line 5 column 3, line 64 - column 4, line 4	45, 46

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